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# INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

**(51) International Patent Classification 6 :** H01F 27/28

A2

**(11) International Publication Number:** WO 99/17311

**(43) International Publication Date:** 8 April 1999 (08.04.99)

**(21) International Application Number:** PCT/SE98/01744

**(22) International Filing Date:** 29 September 1998 (29.09.98)

**(30) Priority Data:**
9703558-8 30 September 1997 (30.09.97) SE

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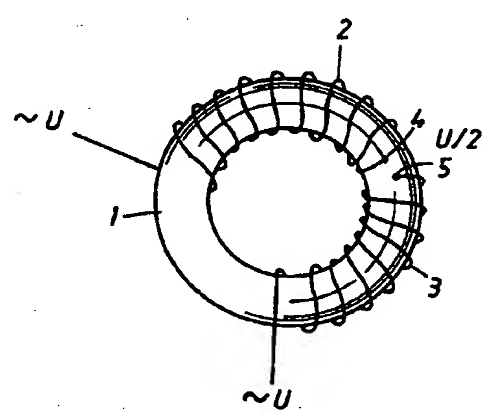
**(81) Designated States:** AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, CZ (Utility model), DE, DE (Utility model), DK, DK (Utility model), EE, ES, FI, FI (Utility model), GB, GE, GH, GM, HR, HU, ID, IL, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SK (Utility model), SL, TJ, TM, TR, TT, UA, UG, US, UZ, VN, YU, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

**Published**
*In English translation (filed in Swedish).*
*Without international search report and to be republished upon receipt of that report.*

**(54) Title:** TRANSFORMER/REACTOR




**(57) Abstract**

The invention refers to a power transformer/reactor having a high voltage winding (2, 3) wound around a core (1). The transformer/reactor is a so-called dry type of transformer, i.e. air-cooled. According to the invention the high voltage winding is divided into a first section (2) and a second section (3) in series to each other. The winding is electrically connected (4, 5) to the core (1) between both these sections.

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# TRANSFORMER/REACTOR

## Technical field

The present invention refers to a power transformer/reactor as defined in the preamble of Claim 1.

For all transmission and distribution of electric energy, transformers are used and their task is to allow exchange of electric energy between two or more electric systems having generally different voltage levels. Transformers are available in all power ranges from the VA up to the 1000 MVA range. With respect to the voltage range, there is a spectrum up to the highest transmission voltages which are being used today. Electromagnetic induction is used for the transmission of energy between the electric systems.

Reactors are also an essential component for the transmission of electric energy, in for example phase compensation and filtering.

The transformer/reactor relating to the present invention belongs to the so-called power transformers/reactors having rated outputs ranging from a few hundred kVA to in excess of 1000 MVA and rated voltages ranging from 3-4 kV up to very high transmission voltages in the rating of up to 800kV.

## Background art

From a purely general point of view, the primary task of a power transformer is to enable the exchange of electric energy, of mostly different voltages with the same frequency, between two or more electric systems.

A conventional power transformer, of for example the type described on pages 2-53 in "*Elkrafthandboken*" (Libers Förlag, Arlöv 1996), comprises a transformer core, referred to below as core, made of laminated sheet preferably oriented sheet which is usually made of silicon steel. The core consists of a number of core legs connected by yokes. A number of windings, normally referred to as primary, secondary and regulating winding, are provided around the core legs. In power transformers these windings are practically always arranged in concentric configuration and distributed along th length of the core leg.

Other types of core constructions occasionally occur such as those of the so-called shell-type transformers or the toroidal-type transformers. Examples of the core constructions are described among other things in DE 40414. The core may consist of conventional magnetizable material such as said oriented sheet, or it may consist of other magnetizable material such as ferrites, amorphous material, wire strands or metal tape. As known, the magnetizable core is not necessary with respect to reactors.

The aforementioned windings constitute one or several coils connected in series constructed of a number of turns connected in series. The turns of a single coil normally make up a geometrically continuous unit which is physically separated from the remaining coils.

The insulation system, partly on the inside of a coil/winding and partly between coils/windings and other metal parts, is normally in the form of a solid cellulose or a varnish based insulation which is closest to the separate conducting means, and the insulation system on the outside is in the form of a solid cellulose and a fluid insulation, possibly also a gas insulation. Windings having an insulation and possible bulky parts correspondingly represent large volumes that will be subjected to high electric field strengths occurring in and around the active electromagnetic parts belonging to the transformer. A detailed knowledge of the properties of the insulation materials is required in order to predetermine the dielectric field strengths which arise and in order to attain a dimensioning such that there is a minimal risk of electric breakdown. Furthermore, it is essential to achieve a surrounding environment which does not change or lead to deterioration of the insulation properties.

Today's predominant outer insulation system for conventional high voltage power transformers/reactors consists of cellulose material as the solid insulation and transformer oil as the fluid insulation. Transformer oil is based on so-called mineral oil.

Additionally, conventional insulation systems of the aforementioned transformers are relatively complicated to construct and special measures need to be taken during manufacture in order to utilise the good insulation properties of the insulation system.

Power transformers for the lower part of the aforementioned power ranges are at times designed having air-cooling in order to remove the inevitable losses in the form of heat. Most power transformers are however oil-cooled and then as a rule by means of so-called forced oil-cooling. This applies especially to high power transformers. Oil-cooled transformers present a number of well known disadvantages. They are among other things large, clumsy and heavy contributing especially to great transport problems and extensive requirements need also to be met with respect to security and auxiliary equipment.

However, it is apparent that replacing oil-cooled power transformers with dry transformers of a new type is possible to a great extent. This new dry transformer is provided with a winding which is designed as a high voltage cable i.e. a high voltage insulated electric conductor. Dry transformers may thus be used at considerably higher powers than what was previously possible. The designation dry transformer and reactor respectively relates thus to a transformer/reactor which is preferably air-cooled and not oil-cooled.

With regard to reactors, these comprise a core which is provided with only one winding and possible regulating windings. In other respects, the aforementioned regarding transformers is substantially relevant to reactors. It is should be particularly noted that even large reactors are oil-cooled.

The insulation around the windings of a dry transformer in the higher power ranges requires great deal of space and is costly in order to maintain a satisfactory insulation against the core. This in turn has the effect of enlarging both The length of the windings as well as the dimension of the core are in turn large in order to create room for the necessary number of winding turns.

The present invention is directed towards this aspect and the aim to try to reduce the thickness of the insulation of the windings and at the same time retaining enough insulation against the core.

Summary of the invention

This aim in accordance with the invention is achieved by means of a transformer/reactor of the type d scribed in the preambl of Claim 1 and by the

characteristic features of the transformer/reactor being defined in the characterizing part of the Claim.

Due to the high voltage winding being electrically connected to the core at one point along the length of the winding, the obtains the corresponding potential in relation to earth. The maximal voltage, occurring between the conductors in the winding and the core, is thereby reduced. In a power transformer/reactor not having this type of connection the maximal voltage Umax between the conductor of the winding and the core equals the supply voltage U, whereas the rated voltage of the embodiment according to the invention rests at the interval Umax>U/2 where the value of Umax depends on where on the winding the contact to the core is established. This means that the insulation required around the conductor decreases to a corresponding degree. A power transformer/reactor according to the present invention may thereby be designed with less insulation around the conductors of the winding. The cost for the winding is thereby reduced. The diameter of the winding is consequently less resulting also in the winding length decreasing since the diameter of the winding turn on the outside decreases due to the turn on the inside taking less space. The dimensions of the core also decrease since leaner dimensions of the winding result in more space in the window so that the window may be made correspondingly smaller. This leads all in all to a substantial reduction in costs compared to a conventional power transformer/reactor of the same rated power in addition to the transformer/reactor becoming far smaller.

The invention is primarily intended to be used for high powers, in the range of 120 MVA and more. At such powers it is preferable to use a high voltage cable in the windings, which cable facilitates attaining a power level in also a dry transformer.

The high voltage cable comprises one or several conductors which are surrounded by solid insulation consisting of at least two semiconducting layers with solid insulation between the layers.

According to a preferred embodim nt of the invention the connection between the conductor in th winding and the core is made at the centre of the winding, i. e. so that the s ctions of the winding on ach sid of the connection have

the same amount of winding turns. This implies an optimal exploitation of the invention concept since the rated voltage between the conductor and the core will then rest at the lower limit of the interval referred to above, i. e. U/2. By means of this embodiment, the greatest possibility of reducing the thickness of the insulation layer around the conductor in the winding is achieved. Another advantage of this embodiment is that the potential of the core will be constant = U/2.

The core, according to a preferred embodiment, is supported by supporting insulators which insulate the core against earth since the core of a power transformer/reactor according to the invention will have a potential against earth.

At least the outer semiconducting layer should form an equipotential surface, most suitably with a potential corresponding to the potential of the core, i. e. half of the supply voltage.

The low voltage winding in transformer applications is according to a preferred embodiment also electrically connected to the core at a point which is preferably at the centre of the core.

The greatest advantage thereby is gained in a transformer where the voltage ratio is 2:1, preferably for example 400 kV to 200 kV or in a so-called autotransformer an economy type transformer where the centre tap is connected to the core. An insulating layer in voltage ratios other than 2:1 is preferably applied between the core and the low voltage winding in order to insulate this layer against the core.

The transformer/reactor is primarily adapted to single-phase application.

The aforementioned and other preferred embodiments of the invented power transformer/reactor are specified in the dependent claims referring to Claim 1.

The insulated conductor or cable used in the present invention is flexible and of a kind which is described in more detail in WO 97/45919 and WO 97/45847. Additional descriptions of the insulated conductor or cable concerned can be found in WO 97/45918, WO 97/45930 and WO 97/45931.

Accordingly, the windings, in the arrangement according to the invention, are preferably of a type corresponding to cables having solid, extruded insulation, of a type now used for power distribution, such as XLPE-cables or cables with

EPR-insulation. Such a cable comprises an inner conductor composed of one or more strand parts, an inner semiconducting layer surrounding the conductor, a solid insulating layer surrounding this and an outer semiconducting layer surrounding the insulating layer. Such cables are flexible, which is an important property in this context since the technology for the arrangement according to the invention is based primarily on winding systems in which the winding is formed from cable which is bent during assembly. The flexibility of an XLPE-cable normally corresponds to a radius of curvature of approximately 20 cm for a cable with a diameter of 30 mm, and a radius of curvature of approximately 65 cm for a cable with a diameter of 80 mm. In the present application the term "flexible" is used to indicate that the winding is flexible down to a radius of curvature in the order of four times the cable diameter, preferably eight to twelve times the cable diameter.

The winding should be constructed to retain its properties even when it is bent and when it is subjected to thermal or mechanical stress during operation. It is vital that the layers retain their adhesion to each other in this context. The material properties of the layers are decisive here, particularly their elasticity and relative coefficients of thermal expansion. In an XLPE-cable, for instance, the insulating layer consists of cross-linked, low-density polyethylene, and the semiconducting layers consist of polyethylene with soot and metal particles mixed in. Changes in volume as a result of temperature fluctuations are completely absorbed as changes in radius in the cable and, thanks to the comparatively slight difference between the coefficients of thermal expansion in the layers in relation to the elasticity of these materials, the radial expansion can take place without the adhesion between the layers being lost.

The material combinations stated above should be considered only as examples. Other combinations fulfilling the conditions specified and also the condition of being semiconducting, i.e. having resistivity within the range of $10^{-1}$-$10^{6}$ ohm-cm, e.g. 1-500 ohm-cm, or 10-200 ohm-cm, naturally also fall within the scope of the invention.

The insulating layer may consist, for example, of a solid thermoplastic material such as low-density polyethylene (LDPE), high-density polyethylene (HDPE), polypropylene (PP), polybutylene (PB), polymethyl pent ne ("TPX"),

cross-linked materials such as cross-linked polyethylene (XLPE), or rubber such as ethylene propylene rubber (EPR) or silicon rubber.

The inner and outer semiconducting layers may be of the same basic material but with particles of conducting material such as soot or metal powder mixed in.

The mechanical properties of these materials, particularly their coefficients of thermal expansion, are affected relatively little by whether soot or metal powder is mixed in or not - at least in the proportions required to achieve the conductivity necessary according to the invention. The insulating layer and the semiconducting layers thus have substantially the same coefficients of thermal expansion.

Ethylene-vinyl-acetate copolymers/nitrile rubber (EVA/NBR), butyl graft polyethylene, ethylene-butyl-acrylate copolymers (EBA) and ethylene-ethyl-acrylate copolymers (EEA) may also constitute suitable polymers for the semiconducting layers.

Even when different types of material are used as base in the various layers, it is desirable for their coefficients of thermal expansion to be substantially the same. This is the case with the combination of the materials listed above.

The materials listed above have relatively good elasticity, with an E-modulus of E<500 MPa, preferably <200 MPa. The elasticity is sufficient for any minor differences between the coefficients of thermal expansion for the materials in the layers to be absorbed in the radial direction of the elasticity so that no cracks appear, or any other damage, and so that the layers are not released from each other. The material in the layers is elastic, and the adhesion between the layers is at least of the same magnitude as in the weakest of the materials.

The conductivity of the two semiconducting layers is sufficient to substantially equalize the potential along each layer. The conductivity of the outer semiconducting layer is sufficiently high to enclose the electrical field within the cable, but sufficiently low not to give rise to significant losses due to currents induced in the longitudinal direction of the layer.

Thus, each of the two semiconducting layers essentially constitutes one equipotential surfac , and thes layers will substantially enclos th el ctrical field between them.

There is, of course, nothing to prevent one or more additional semiconducting layers being arranged in the insulating layer.

The invention will now be described in detail in the following description of a preferred embodiment with reference to the accompanying drawings.

Brief description of the drawings

Figure 1 is an end view showing the principle of a transformer according to the invention.

Figure 2 is a side view showing the principle of the transformer of Figure 1

Figure 3 is a cross-section of a high voltage cable being used in the transformer of Figure 1.

Figure 4 shows the principle of a transformer according to an alternative embodiment of the invention.

Detailed description of the preferred embodiment of the invention

The power transformer shown in Figure 1 has a toroidal type of core 1. Other types of cores are naturally feasible within the frame of the concept of the invention. The core, irrespective of its construction, is of a conventional type and may be constructed in the prevalent way and therefore a further description is possibly required. The transformer is a dry transformer, i. e. a transformer not having an oil based cooling system.

A high voltage winding and a low voltage winding are provided around the core whereby for clarity sake only the high voltage winding is shown. The high voltage winding may conceivably form the main winding of the transformer. The transformer is supplied with the voltage U on the high voltage side and operates in the power range of 120 MVA and more. The high voltage winding is divided into a first 2 section and a second 3 section and the conductor of the winding where the two sections meet is electrically connected to the core 1 at the contacts 4, 5. Each section 2, 3, has the same amount of winding turns so that the contact points to the core divide the winding in two. The core 2 will then obtain a potential to earth which is equal to half the supply voltage, i. e. U/2. Th potential to earth will in principle r st constantly at this value. The voltag difference b tween the conduc-

tors in the winding and the core will thereby increase to maximally U-U/2 =U/2. The voltage difference decreases thereafter towards the contact points where the difference is equal to zero.

High demands are placed on the insulation of the windings since the transformer operates at high voltage and with high power. The insulation need is considerably reduced by means of the invention, but the voltage levels are nevertheless relatively high. The winding is designed as a high voltage cable of the type shown in Figure 3 in order to meet these requirements.

The core is supported by supporting insulators 6 such as shown in Figure 2 in order to insulate the core against earth 7.

Figure 3 shows a cross-sectional view of a high voltage cable 2, 3 according to the present invention. The high voltage cable 2, 3 comprises a plurality of strands 31, having a circular cross-section, of for example copper (Cu). These strands 31 are arranged in the centre of the high voltage cable 2,3. Around the strands 31 there is arranged a first semiconducting layer 32. Around the first semiconducting layer 32 there is arranged an insulation layer 33, of for example XLPE-insulation. Around the insulation layer 33 there is arranged a second semiconducting layer 34. Each semiconducting layer 32, 34 forms an equipotential surface when the cable is arranged in the transformer in operation. Both semiconducting layers 32, 34 have primarily the same coefficient of thermal expansion as the insulation layer 33.

In Figure 3, showing the detail relating to the insulated conductor or cable, the three layers are arranged to adhere to each other even when the cable is bent. The cable shown is flexible, and this property of the cable is maintained during the entire life of the cable.

Figure 4 shows schematically how an insulating layer 10 is arranged between the low voltage winding 8, 9 and the core 1 in a transformer according to an alternative embodiment of the invention.

CLAIMS

1. A dry power transformer/reactor having a high voltage winding (2, 3) wound around a core (1) **characterized** in that the high voltage winding (2, 3) is divided into a first (2) section and a second (3) section, which sections are in series to each other and electrically connected (4, 5) to the core (1) between the first (2) and the second (3) section, the high voltage winding (2, 3) being formed of a high voltage cable, comprising one or several current-carrying conductors (31) and a solid insulation system comprising at least two semiconducting layers (32, 34), between which layers (32, 34) there is arranged solid insulation (33).

2. A power transformer/reactor according to claim 1, where the first (2) section and the second (3) section have primarily the same amount of winding turns.

3. A power transformer/reactor according to claim 1 or claim 2, where insulation means (6) are arranged to support the core (1) and means (6) are arranged to insulate the core against earth (7).

4. A power transformer/reactor according to any one of claims 1-3, where the outer semiconducting layer (34) substantially forms an equipotential surface.

5. A power transformer/reactor according to claim 4, where said equipotential surface has a potential to earth corresponding to half of the voltage of the high voltage winding.

6. A power transformer/reactor according to any one of claims 1-5, where at least one of the semiconducting layers (32, 34) has primarily the same coefficient of thermal expansion as the solid insulation (33).

7. A power transformer/reactor according to any one of claims 1-6, where the conductor area of the cable is between 50 mm$^2$ and 3000 mm$^2$ and where the outer diameter is between 20 mm and 250 mm.

8. An power transformer/reactor according to any one of claims 1-7, **characterized** in that said layers (32, 33, 34) are arranged to adhere to one another even when the cable is bent.

9. A power transformer/reactor according to any one of claims 1-8, where the power transformer/reactor is arranged for a rated power of at least 120 MVA and a voltage of at least 3 kV.

10. A power transformer according to any one of claims 1-9 which also comprises a low voltage winding wound around the core (1) whereby the low voltage winding is also divided into a first section and a second section which are in series with each other and where the low voltage winding is electrically connected to the core between the first section and the second section.

11. A power transformer according to claim 10, where the first section and the second section of the low voltage winding have primarily the same amount of winding turns.

12. A power transformer according to claims 1-8 or claim 10 or 11, where the voltage ratio is substantially 2:1.

13. A power transformer according to any one of claims 1-12, where the transformer is designed as a balancing transformer.

14. A power transformer according to any one of claims 1-13, where an insulating layer is arranged between the low voltage winding and the core.

Fig.1

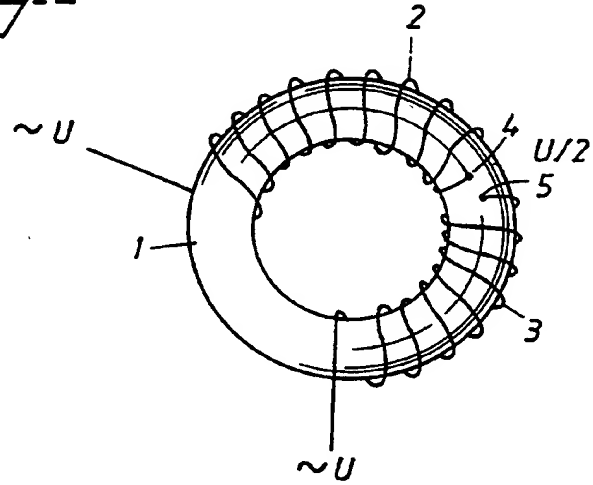


Fig.2

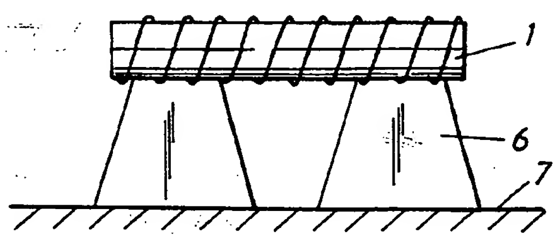


Fig.3

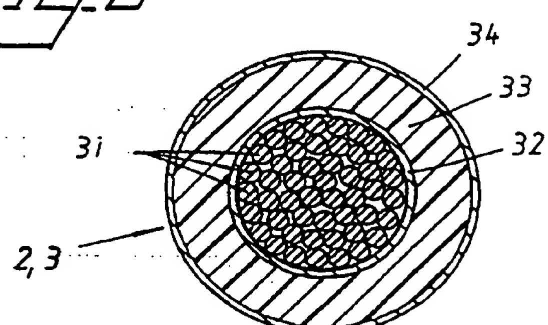

Fig. 4